National Aeronautics and Space Administration

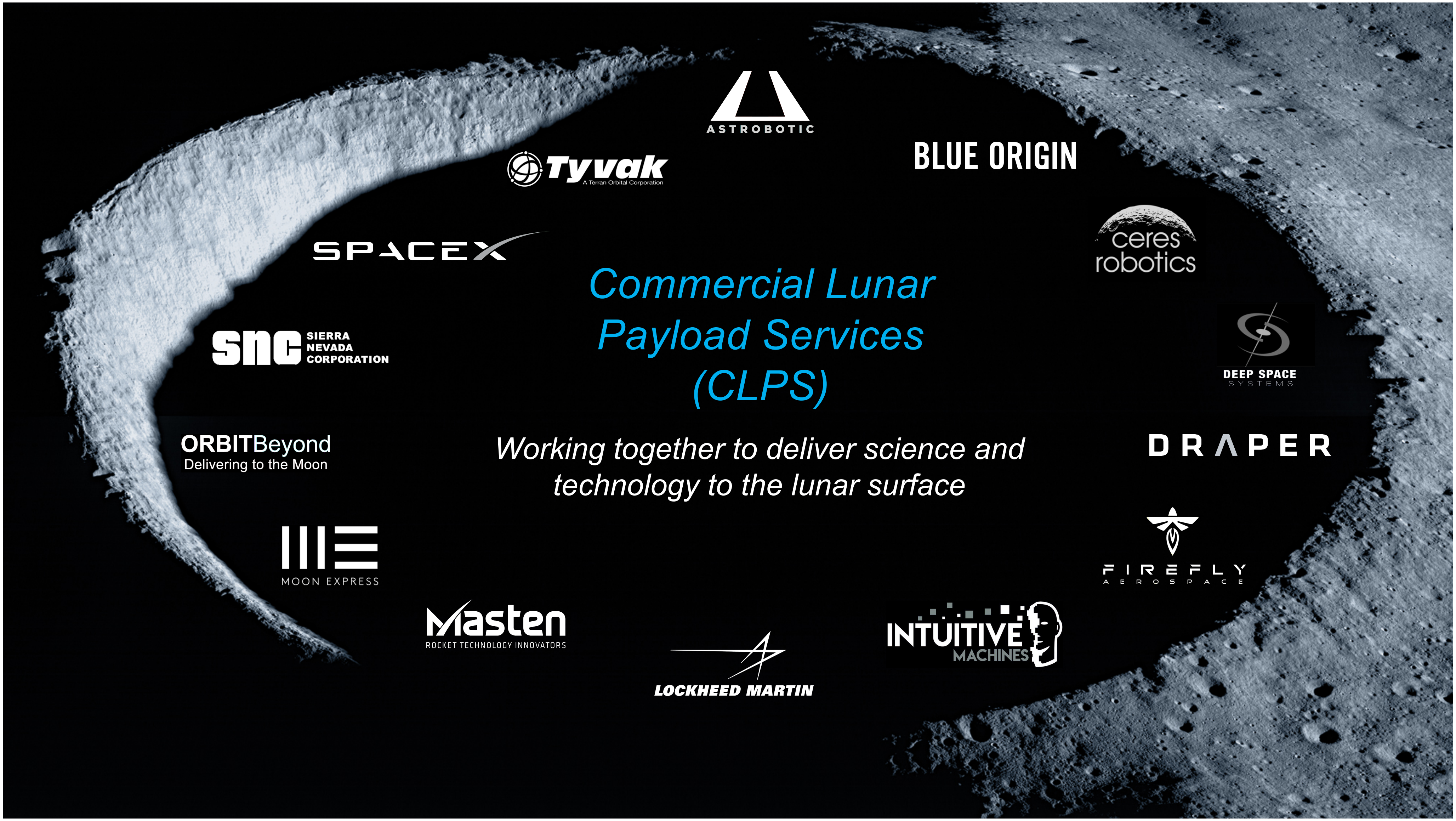
EXPLORE SCIENCE

Lunar Program

Steve Clarke
Deputy Associate Administrator for Exploration
NASA Science Mission Directorate

Planetary Science Advisory Committee Meeting

March 9, 2020


ASTROBOTIC
Tyvak
A Terran Orbital Corporation
BLUE ORIGIN
SPACEX
ceres robotics
Commercial Lunar Payload Services (CLPS)
SNC SIERRA NEVADA CORPORATION
DEEP SPACE SYSTEMS
ORBITBeyond
Delivering to the Moon
Working together to deliver science and technology to the lunar surface
DRAPER
MOON EXPRESS
FIREFLY AEROSPACE
Masten
ROCKET TECHNOLOGY INNOVATORS
INTUITIVE MACHINES
LOCKHEED MARTIN

Commercial Lunar Payload Services (CLPS) Summary

- **Task Order 2 - Astrobotic (NPLP + HEO/STMD in-line tech demos)**
  - Lunar delivery September 2021
- **Task Order 2 – Intuitive Machines (NPLP + STMD in-line tech demo + STMD data buy)**
  - Lunar delivery October 2021
- **Task Order 19C (LSITP + NPLP 2nd's)**
  - Will deliver LSITP payloads and some NPLP second copies to a Lunar Pole in late 2022.
  - Request for Task Order Proposal (RFTOP) proposals received March 4; Selection by the end of March.
- **Task Order 20A (VIPER)**
  - RFTOP released February 25 with proposals due April 10 and award late mid/late May.
    - Delivery lunar surface delivery to late-2023 with a mid-2023 accelerated option.
- **Task Order 19D (Second LSITP)**
  - Will deliver additional payloads from LSITP and tech demos to a non-polar location in early 2023.
  - RFTOP release planned for June/July 2020 timeframe.

2021 CLPS Delivery Manifests

Payloads largely selected from NASA Provided Lunar Payloads (NPLP)

Astrobotics Lander

- Surface Exosphere Alterations by Landers (SEAL)
- Photovoltac Investigation on Lunar Surface (PILS)
- Near-Infrared Volatile Spectrometer System (NIRVSS)
- Mass Spectrometer Observing Lunar Operations (Msolo)
- PROSPECT Ion-Trap Mass Spectrometer for Lunar Surface Volatiles (PITMS)
- Linear Energy Transfer Spectrometer (LETS)
- Neutron Spectrometer System (NSS)
- Neutron Measurements at the Lunar Surface (NMLS)
- Fluxgate Magnetometer (MAG)
- Navigation Doppler Lidar for Precise Velocity and Range Sensing (NDL)

Key

Science	green
Technology	yellow
Exploration	blue
HEOMD/STMD	red

Intuitive Machines Lander

- Lunar Node 1 Navigation Demonstrator (LN-1)
- Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)
- Low-frequency Radio Observations from the Near Side Lunar Surface (ROLSES)
- Navigation Doppler Lidar for Precise Velocity and Range Sensing (NDL)
- Radio Frequency Mass Gauge (RFMG)

Payloads largely selected from Lunar Surface Instrument and Technology Payloads (LSITP)

Provisional 2022 CLPS Delivery Manifests

Polar

- Sample Acquisition, Morphology Filtering & Probing of Regolith (SAMPLR)
- Camera System for lunar science on commercial vehicles (Heimdall)
- Near-Infrared Volatile Spectrometer System (NIRVSS)
- Linear Energy Transfer Spectrometer (LETS)
- Lunar Compact Infrared Imaging System (L-CIRiS)
- Moon Rover with Exploration Autonomy (Moon Ranger)
- Laser Retroreflector
- Mass Spectrometer Observing Lunar Operations (Msolo)
- Neutron Spectrometer System (NSS) – Deployed on Moon Ranger

Key

- Science
- Technology
- Exploration

Crisium

- Lunar Environment Heliophysics X-Ray Imager (LEXI)
- Next Generation Lunar Retroreflectors (NGLR)
- Radiation Tolerant Computer System
- Sample Acquisition & Delivery System for Instruments & Sample Return (PlanetVac)
- Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER)
- Lunar Magnetotelluric Sounder (LMS)
- Regolith Adherence Characterization (RAC)

PRISM Overview

- Future Payloads and Research Investigations on the Surface of the Moon (PRISM) solicitation planned approximately annually
  - ➢ 2-stage process. Stage 1 is an open RFI expected in March 2020
  - ➢ The PRISM Open RFI will result in a catalog of available instruments that will aid in determining future landing sites for CLPS deliveries.
  - ➢ PRISM NRA solicitations will state the location for each delivery, allowing PIs to propose science optimized for those locations
    - ❑ The initial priority for PRISM is to solicit suites of instruments that can work together
    - ❑ High-value ‘location agnostic’ instruments also welcome
  - ➢ Selected PRISM instruments would feed the manifests for Task Orders for deliveries from 2023 onwards
    - ❑ International payloads, and payloads from other NASA mission directorates also could be incorporated into the Task Order
  - ➢ The PRISM Open RFI also will create a catalog of instruments from which we can choose to fill out other flight opportunities, either commercial or international
  - ➢ Expect to have Participating Scientist Programs for each flight
  - ➢ Subsequent PRISM calls will ask for destination agnostic and stand-alone instruments, in addition to science campaigns with multiple landers

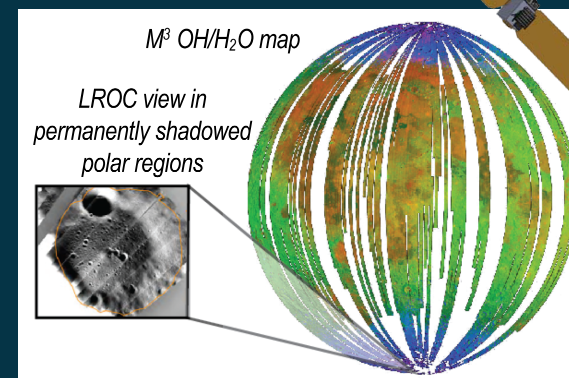
Lunar Trailblazer

- **Addresses major scientific questions about the Moon and water cycles on airless bodies directly from the Planetary Science Decadal Survey.**
- **Forges a path for future exploration by evaluating locations of the operationally useful deposits of water and providing compositional basemaps of landing zones**

Lunar Trailblazer (5-m w/ panels deployed)

An **ESPA-Grande sized craft**, deployable from any GTO orbit, Trailblazer uses nested measurement sets from

1) **High-resolution Volatiles and Minerals Moon Mapper (HVM³):** a JPL-built imaging spectrometer (0.6-3.6 µm)
2) **Lunar Thermal Mapper (LTM):** University of Oxford-built multispectral thermal camera (7-100 µm)
   to **determine the form, abundance, and distribution of water on the Moon**. Distribution is mapped a function of latitude, time-of-day, soil maturity, and lithology. Terrain-scattered light is used to map in permanently shadowed craters. Bonus science: compositional maps of igneous lithology



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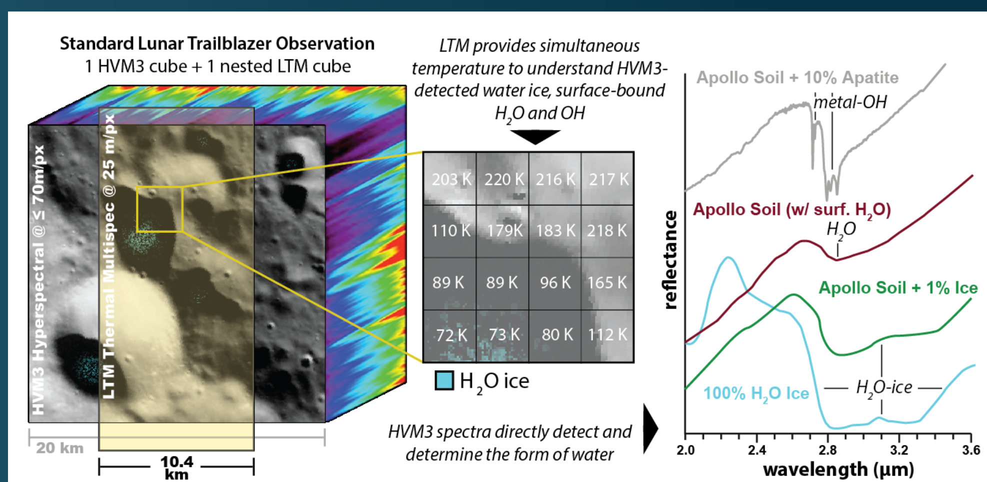
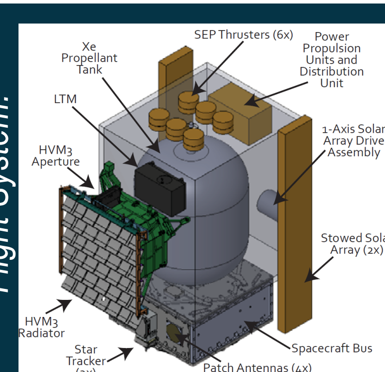


Flight System:



Lunar Mobility Strategy

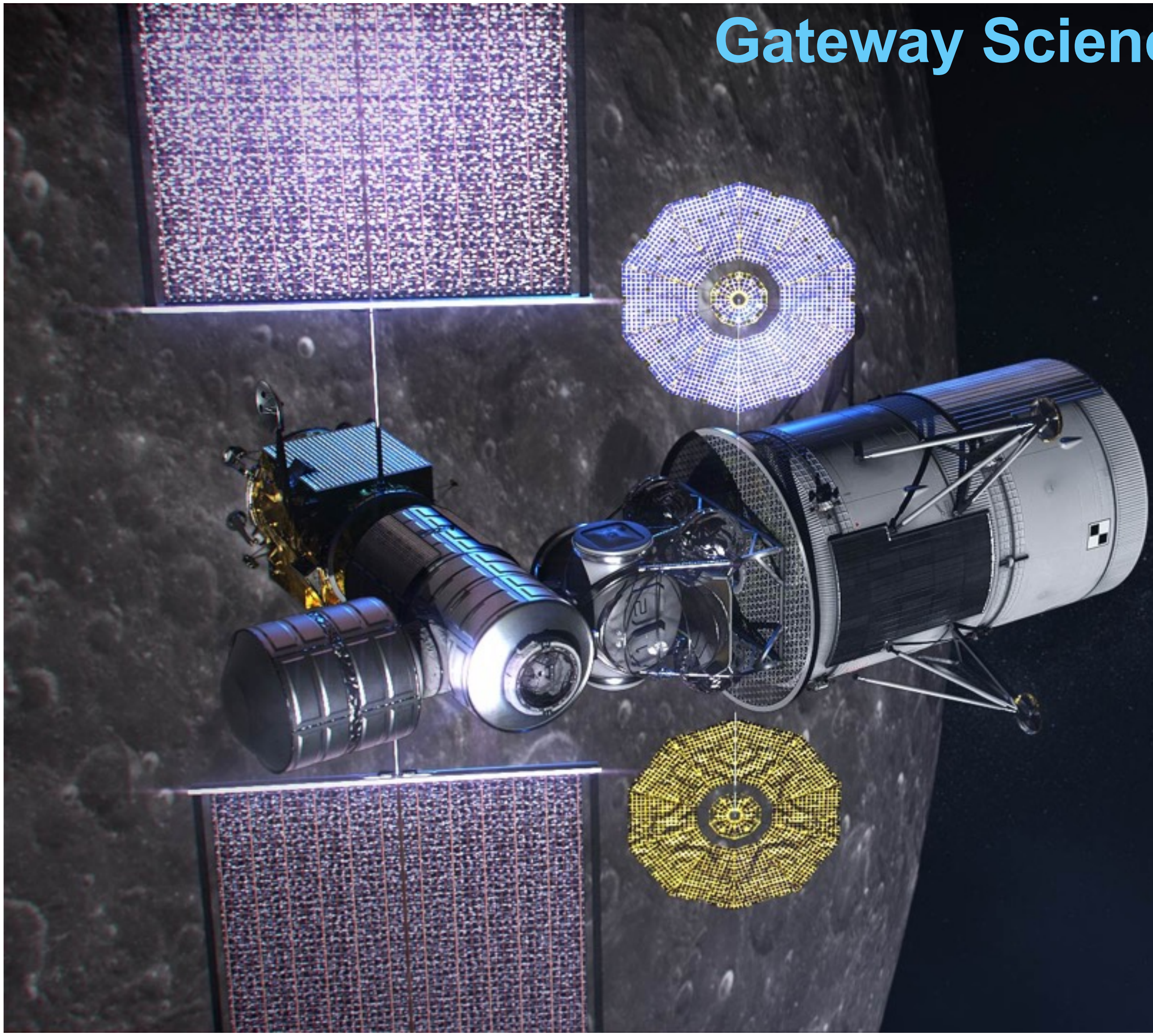
Primary objectives

- Ground truth of volatiles (horizontal and vertical distribution, composition, and form)
- Long duration operation (months)

Parallel Mobility Development Paths

- ✓ Study task order to existing CLPS providers
- ✓ NASA in-house development (VIPER)
- ✓ Investigate international contribution (e.g., ESA, CSA)
- ✓ RFI to industry to determine potential commercial sources and availability
  - Inputs received March 6

Gateway Science



- **Opportunities to fly science instruments on Gateway elements continue to be discussed.**
- **Candidate Space Weather Science Instrument Suite on the Power & Propulsion Element (PPE) would:**
  - Investigate solar energetic particle acceleration mechanisms and solar wind structure dynamics
  - Study magnetotail dynamics energy input to the magnetosphere during geomagnetic storms
  - Enable improved space weather forecasting capability at the Moon which will also baseline the needed capabilities for future crewed missions to Mars
  - Enhance astronaut safety by providing critical information for guiding crew mitigation actions

DAAX Internal and External Engagement

Internal Engagements

- The DAAX Program Scientist is member of Human Landing System (HLS) Source Evaluation Board
  - Moving into the final review phase for down-selection
- Planning the SMD/HEOMD/STMD Lunar Surface Science Workshop to be held in Denver April 28-30 Postponed
  - Over 170 abstracts received
- DAAX leading SMD integration efforts for payload ingest onto Gateway modules
  - Working with Heliophysics on a suite of instruments selected for attachment to one of the external Gateway instrument slots
- Integral part of the Moon to Mars strategy. Strategy is SMD led in conjunction with HEOMD and STMD research priorities.

External Engagements

- In negotiations with European Space Agency (ESA) regarding delivering of Pathfinder communications spacecraft into lunar orbit
- In discussions with Canadian Space Agency (CSA) regarding flying two science payloads, and a small rover, on future CLPS deliveries
- In discussions with Korea Astronomy and Space Science Institute (KASI) regarding including KASI payloads on future CLPS deliveries
- Supporting the HEOMD-led International Mobility Study team meeting with Japan Aerospace Exploration Agency (JAXA)
- Agreement with JAXA to include LRA on their SLIM lander
- Working with U.S. Geological Survey (USGS) to discuss an umbrella Interagency Agreement (IAA) where NASA lunar exploration programs can leverage USGS expertise to inform lunar exploration efforts

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Lunar Program

Dr. Brad Bailey
Program Scientist
DAAX Office, Science Mission Directorate

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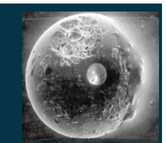
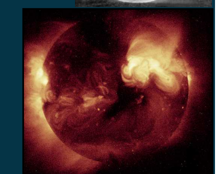
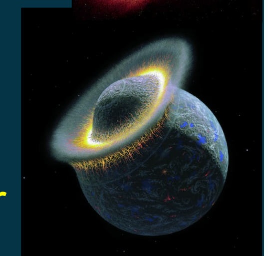
The Moon Enables Scientific Exploration

- A natural laboratory to study planetary processes and evolution, and a platform from which to observe the Universe
  - ➢ The Moon is a cornerstone for Solar System science and for exoplanet studies

- A place to learn how to conduct scientific exploration from a planetary surface
  - ➢ Conducting scientific exploration synergistically with crew and robotic explorers teaches us effective techniques that can be applied as we push the boundaries of exploration

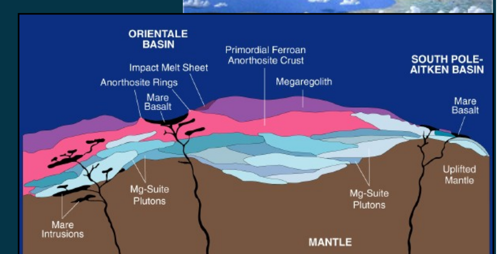
- An opportunity to use emplaced infrastructure and resources
  - ➢ The infrastructure associated with human exploration can be leveraged to support autonomous scientific investigations

The Moon is a Cornerstone for Solar System Science

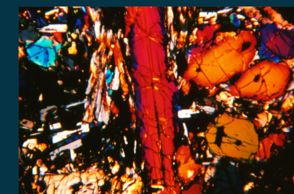




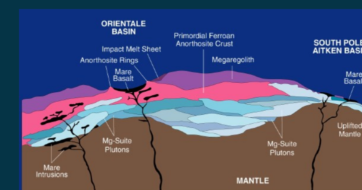

- The high scientific value of the Moon has been captured in a plethora of community driven documents
  - Lunar Exploration Analysis Group’s Lunar Exploration Roadmap
  - National Academies’ Decadal Surveys
  - National Academies' Scientific Context for the Exploration of the Moon
  - International Space Exploration Coordination Group’s Science White Paper
  - Lunar Exploration Analysis Group’s Advancing Science of the Moon

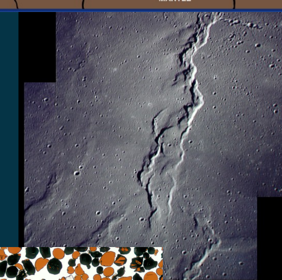
- A number of common scientific themes are found in these documents:
  - Study of Planetary Processes
  - Understanding Volatile Cycles
  - Impact History of the Earth-Moon System
  - Record of the Ancient Sun
  - A Platform to Study the Universe
  - A Place for Fundamental Science in the Lunar Environment

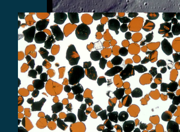


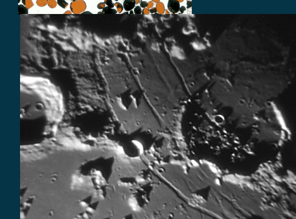
Study of Planetary Processes











- The Moon - a “mini planet” and prime example for planet formation observed around other stars
  - Differentiation - magma oceans, crust, and mantle
  - Impact - basins and craters, mixing of the crust
  - Volcanism - partial melting, eruptions, flow sequence and compositions
  - Tectonism - deformation of the crust and thermal history
  - Volatiles - history, production, and escape mechanisms

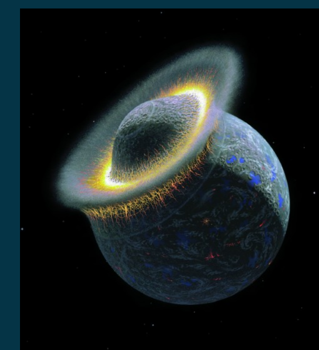
Impact History of the Earth-Moon System

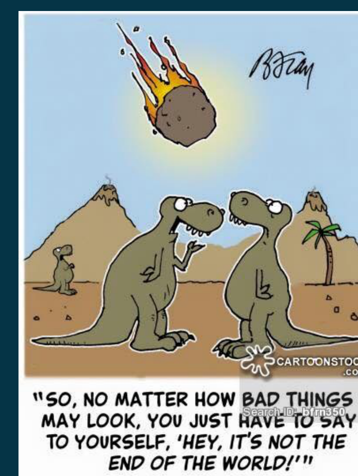
- Craters are erased on the dynamic, eroded surface of Earth. The Moon retains this record

- Both Earth and Moon reside at 1 AU, recording the impact and providing an absolute chronology that anchors the impact history of the inner Solar System

- Impact Episodicity? Cretaceous–Paleogene (K-Pg) impact 65 million years ago wiped out 85% of all fossil species. Incomplete statistics suggest such impacts may occur periodically

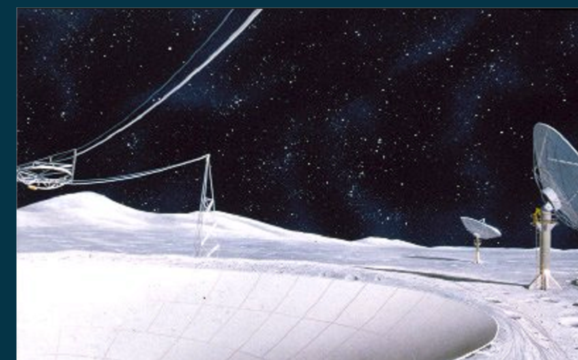
- The Moon’s impact record can be recovered and interpreted in terms of Earth-Moon history





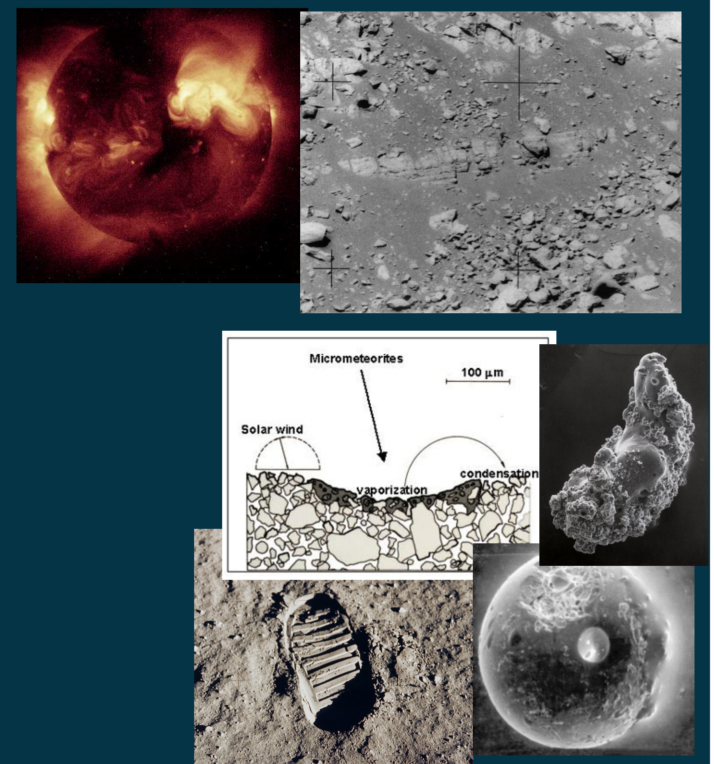
A Platform to Observe the Universe

- The lack of atmosphere allows the full electromagnetic spectrum to be visible from the lunar surface
- The farside of the Moon is the only known place in the Solar System permanently shielded from Earth's radio noise
- Opportunistic astronomy leveraging surface infrastructure



A Record of the Ancient Sun

- The Moon's surface has been bathed in solar wind, cosmic rays throughout its history
- Dust grains retain these particles
- Buried regolith and regolith trapped between lava flows retains the historical record of these fluxes
- Detailed excavation and study by humans can retrieve this record



Science Enabled by the Lunar Environment

- Life sciences - Combined effects of fractional gravity and deep space radiation
- Food/drug degradation
- Combustion science
- Fundamental physics - General relativity, gravitational physics
- Material sciences

Science Strategy at the Moon

- Use Commercial Lunar Payload Services (CLPS) contract to deliver instruments on and near the Moon
  - Volatile measurements are a priority
  - Science at both polar and non-polar locations
  - Drive increased capability including mobility, farside access, and sample return
- Release and award science instrument development opportunities on an annual basis
- Develop an international strategy to enable partner scientific contributions
- Develop an exploration science mission plan for the first human return mission
  - Engage the community to develop ideas for science to conduct on the lunar surface
  - Coordinate with HEOMD to prioritize surface science objectives, develop the necessary tools and terrestrial training to conduct that science
  - Provide potential landing sites analysis including new data acquisition
  - Consider potential pre-deployment of science experiments for the crew to set up
  - A joint SMD/HEOMD/STMD workshop was planned for April 2020 to discuss the science enabled by crews going to the south polar region; postponed due to travel restrictions implemented with continuing coronavirus spread

Science by 2024

- **Polar Landers & Rovers**
  - First direct measurement of polar volatiles, improving understanding of lateral and vertical distribution, physical state
  - First surface exploration of permanently shadowed regions

- **Non-Polar Landers & Rovers**
  - Explore scientifically valuable terrains not investigated by Apollo. Examples could include young volcanic areas, magnetic anomalies, pyroclastic deposits, farside
  - Move to a PI-led CLPS delivered instrument model conducting focused science for a selected location
  - Provide opportunities for international cooperation

- **Orbital data**
  - High-resolution mapping of permanently shadowed regions
  - CubeSats delivered by Artemis I
  - High priority new data sets acquired by CubeSats or SmallSats delivered by CLPS

- **In-Situ Resource Initial Research**
  - Answering questions on composition and ability to use lunar ice for sustainment and fuel

Lunar Surface Science Workshop

A joint SMD/HEOMD/STMD workshop is planned for TBD 2020 to discuss the science enabled by crews going to the south polar region

Topics include

- Which locations within 6° of the South Pole are the highest priority to be visited by the crew, and what science could be achieved?
- What science instrumentation do we want on the surface?
  - Includes both surface science experiments that might need crew interaction to emplace, as well as science instruments to help the crew conduct science
- What technology development is required to enable the crews to conduct the science?
- What infrastructure could enable science?

Advancing Beyond the Apollo Paradigm

- Field Geology
  - Study the origin and evolution of the Earth-Moon system on the lunar surface.
    - The Moon has experienced geologic processes that shape all terrestrial planets: Impact Cratering, Volcanism, and Tectonism.
    - Mobility on the surface is a key factor for enabling a range of scientific activities (*e.g.*, accessing multiple geologic units, deploying experiments over a broad area).
    - Best achieved as a human/robotic partnership.
- New Samples Are Critical
  - The geologic diversity of the Moon coupled with careful selection of samples for return to Earth will address a plethora of science questions.
- Surface Instrumentation
  - Humans facilitate the placement of delicate surface instrumentation
    - Radio experiment on the radio-quiet farside offers a unique opportunity for sensitive measurements of the early Universe.
- Access to Regions with Cold Temperatures
  - Our knowledge of surface temperatures enable a volatile rich sample to be collected.

A Bold New Era of Human Discovery

- An Opportunity to Study Planetary Processes
  - Mobility to visit geologically different features
  - Extravehicular Activity (EVA) traverses and suits designed for strategic sample collection
- A Critical Location to Understand Volatiles Cycles
  - Access to persistently shadowed terrain (either robotically or with crew)
  - Sealed collection canisters designed for cold sample curation and volatile sampling
- Impact History of the Earth-Moon System
  - Collection of several walnut-sized rocks for chronologic analyses on Earth
  - Identification of, and collection of rocks from, outcrops and boulders
- Record of the Ancient Sun
  - Collection of core tube samples to capture ancient solar wind trapped in regolith layers
  - Understanding regolith stratigraphy
- A Stable Platform to Study the Universe
  - Dexterity to deploy delicate instrumentation
  - Characterization of the local environment (dust, RF, plasma)